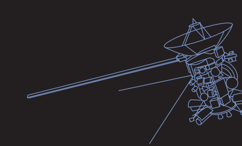


CAPTURING A *Whisper* FROM SPACE

DEEP SPACE NETWORK

Teachers — Curriculum activities on the reverse can be downloaded from http://deepspace.jpl.nasa.gov/dsn/educ/poster.html

Deep Space Network Web Site — http://deepspace.jpl.nasa.gov

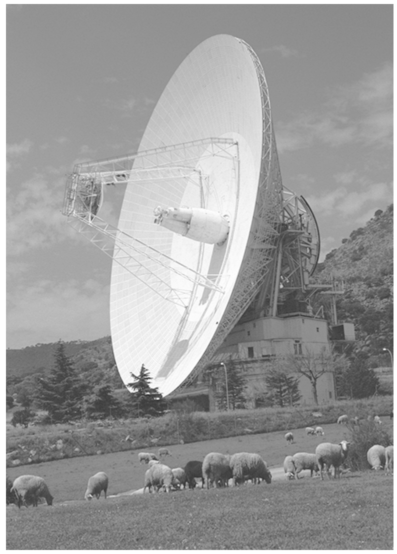
THE NASA VISION

To improve life here,
To extend life to there,
To find life beyond.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 400-1072 02/03
EW-2003-02-014-JPL

The National Aeronautics and Space Administration (NASA) has been sending robotic spacecraft out into the solar system for more than four decades. These mechanical explorers have ventured out to study Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and Neptune. These amazing robots have been our eyes and ears on their journeys to far-off planets and even to the edge of the solar system, sending wondrous images and fascinating information back to Earth.



The largest antennas in the Deep Space Network are the 70-meter-diameter dishes — there is one at each of the three complexes. This one is in Spain. All the complexes have additional antennas of varying sizes.

But none of these missions of discovery would have been possible without the Deep Space Network — a worldwide system of sensitive antennas that communicates with NASA's interplanetary spacecraft. Signals to and from the spacecraft travel millions, even billions, of kilometers. Yet spacecraft communications equipment transmits signals at very low power, usually about 20 watts, about the same as a refrigerator light bulb. As the signal travels to Earth, it continues to lose energy, and signals arriving at the antennas on Earth can be as weak as a billionth of a billionth of a watt — that is 20 billion times less than the power required for a digital wristwatch. How is it possible to hear the tiny whisper of a signal from a spacecraft so far away?

The Deep Space Network is made up of complexes of antennas in three locations on the globe — Goldstone, California (in the Mojave Desert); near Canberra, Australia; and near Madrid, Spain. This arrangement compensates for Earth's rotation so that a distant spacecraft is in view of one of the Deep Space Network's antenna complexes 24 hours a day. The spacecraft signals are received at one site; as Earth turns, the spacecraft "sets" (like the Sun setting each night) and the next site picks up the signal, then the third site, and then the first again.

To hear the low-power spacecraft signal, receiving antennas on Earth must be very large, with extremely sensitive receivers. The signal from the spacecraft travels in a straight line, and it can be focused by a curved reflector dish (parabolic antenna), so large antenna dishes with precisely shaped surfaces are crucial. The Deep Space Network's parabolic dishes are focusing mechanisms that concentrate power when receiving data and also when transmitting commands. The antennas must point very accurately towards the spacecraft, because an antenna can "see" only a tiny portion of the sky (as though looking at the sky through a soda straw).

To hear the spacecraft's faint signal, the antennas are equipped with amplifiers, but there are two problems. First, the signal becomes degraded by background radio noise (static) emitted naturally by nearly all objects in the universe, including the Sun and Earth. The background noise gets amplified along with the signal. Second, the powerful electronic equipment amplifying the signal adds noise of its own. The Deep Space Network uses highly sophisticated technology, including cooling the amplifiers to a few degrees above absolute zero, and special coding techniques so the receiving system can distinguish the signal from the unwanted noise.

New space missions bring new challenges. NASA's Deep Space Network is continually improved and enhanced to provide communications, navigation, and tracking for distant spacecraft — our robot explorers of the cosmos.

Educators —
Please take a moment to evaluate this product at http://ehb2.gsfc.nasa.gov/edcats/educational_wallsheet
Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

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When people think of working in space, they usually think of astronauts going to the Moon or building the International Space Station. In fact, thousands of people work in the space program, but stay on planet Earth — and they are not all scientists or spacecraft engineers. Many types of skills, and many types of individuals, are needed to make the space program a success. Here are the stories of just a few of the people who work in NASA's Deep Space Network.

I'm **David**, and I'm a member of the Navigation and Mission Design section at the Jet Propulsion Laboratory. We analyze spacecraft data that we use to fly the spacecraft from Earth, navigate them through space, and get them to planets, moons, and comets. My job is to help determine where the Mars Global Surveyor and Mars Odyssey spacecraft have been, their present positions and speed, and where they will be in the future. This information is useful to scientists who want to know where to position their instruments (such as cameras and other sensors) on board the spacecraft. I have a Bachelor of Science degree in aeronautics/astronautics from the Massachusetts Institute of Technology.

My name is **Carol** and I develop computer software called the Science Opportunity Analyzer. Scientists use this software to design observations that will be made by the Cassini spacecraft. They simulate the views their instruments on Cassini will "see," and in this way determine the best opportunities to collect data as the spacecraft orbits Saturn on its scientific tour. I enjoy working with the diverse international community of scientists and engineers that make up the Cassini science teams. I have a doctorate in planetary science, a master's degree in geophysics from the California Institute of Technology, and a dual bachelor's degree in physics and astronomy from Pennsylvania State University. I am currently working part-time in order to spend two days a week at home with my four-year-old daughter.

My name is **Ramona**, and I work as a telecom analyst for several JPL missions. My job involves monitoring the health and status of the spacecraft telecommunications subsystem, and ensuring that the spacecraft can communicate with the Deep Space Network at all times, even in an emergency. The part of my job I enjoy most is seeing data appearing on my computer screen, knowing that it is being broadcast by a spacecraft on its way to Mars, Jupiter, Saturn, or even near the edge of the solar system. Some of that data is processed to produce pictures of great scientific importance. I have a bachelor's and a master's degree in electrical engineering from the Massachusetts Institute of Technology.

I am **Alfonso**, and I am the supervisor of the Antenna Mechanical and Structural Engineering Group in charge of all the Deep Space Network ground antennas. My group is in charge of antenna design, analysis of components, and maintenance. I worked on the construction of a new 34-meter-diameter antenna at the Communications Complex in Madrid, Spain, and we are also studying the possibility of constructing a large array of smaller antennas that are each 12 meters in diameter. I received B.S. and M.S. degrees in mechanical engineering from the National University of Mexico and a Ph.D. from the University of Wisconsin–Milwaukee.

My name is **Martin** and I work in the Deep Space Operations Center where I'm the senior data controller. My job is to manage the data coming from deep space and interplanetary spacecraft, including missions to Mars and Saturn, space telescopes, and European missions. I make the data available to scientists, laboratories, and schools around the world. I started my career in the U.S. Air Force working on space and missile electronics. I'm an Air Force reservist at a space operations squadron, where we manage all the military's space assets, such as the Global Positioning System of Earth-orbiting satellites as well as communications and weather satellites. I don't have a degree yet; instead, I have many years of hands-on experience.

Hello all, my name is **Steve** and I work at the Goldstone Deep Space Communications Complex. I work in the operations department where I configure and monitor the subsystems for communicating with and receiving information from spacecraft. A few of these systems are antennas, transmitters, receivers, command, ranging, and telemetry groups. The people in the operations department at Goldstone are required to work on a 24-hour/365-day schedule — because spacecraft never sleep. I track many different spacecraft, including Earth-orbiting satellites as well as spacecraft at Mars, Saturn, Jupiter, and out beyond Pluto. I have been with the Deep Space Network for more than eight years. I have a bachelor's degree in electronic engineering from ITT Technical Institute.

My name is **Jonni** and I work in the Network Operations Control Center at the Jet Propulsion Laboratory. I am responsible for sending information known as support products to the three Deep Space Communications Complexes in California, Spain, and Australia. My job is exciting because I supply information to the sites that tells them where to point the antennas to receive data from the spacecraft, thus ensuring that the various projects receive their scientific data. I am still in school and am working toward a bachelor's degree in computer science.

My name is **Jorge** and I work at the Goldstone Deep Space Communications Complex in the Mojave Desert in California. I troubleshoot and repair digital system equipment that is vital to operations. My job is critical because I'm responsible for the functionality of the antenna pointing and telemetry subsystems. Among the missions I have supported are Mars Odyssey, Voyager, Genesis, and the Solar and Heliospheric Observatory. I have an associate's degree in electronics from ITT Technical Institute.

My name is **Tim**. I am the antenna maintenance specialist for the three NASA Deep Space Network tracking stations located in Canberra, Australia; Madrid, Spain; and Goldstone, California. The tracking antennas at each station are used to upload (send) and download (receive) information and guidance commands to and from numerous spacecraft. My job is to keep the antennas operational. I have a Bachelor of Science degree in engineering technology–welding technology from California Polytechnic State University, San Luis Obispo.

PURPOSE

To give students a mathematical model of how the Deep Space Network antennas work and how the antennas concentrate electromagnetic radio waves in a single direction.

QUESTION

Does the size of an antenna influence wave detection?

LEARNING OBJECTIVES

The students will learn that it takes mathematics to talk to spacecraft:

- Scientists on Earth must communicate information to spacecraft and be able to receive the faint signals from spacecraft that carry new information about the cosmos.
- The parabolic shape of the antenna dish helps to increase the distance at which radio waves can be detected by means of concentration and directionality.
- Sound waves emitted from a source are a good analog for radio waves used to communicate with spacecraft.
- The volume of the sound decreases as the distance from the source increases, according to the inverse square law.

GRADES 6–8 MATHEMATICAL STANDARDS

(from "Principles and Standards for School Mathematics," NCTM, 2000)

This investigation will encourage students to:

- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.
- Recognize and apply mathematics in contexts outside of mathematics.
- Develop and evaluate inferences and predictions that are based on data.
- Use observations about differences between two or more samples to make conjectures about the data sets from which the samples were taken.
- Understand both metric and customary systems of measurement.
- Use representations to model and interpret physical, social, and mathematical phenomena.

ADVANCE PREPARATION

For making parabolic dish antennas, make student copies of the antenna pattern on cardstock and collect recycled 1- to 3-liter soda bottles (one per student). Additionally, make copies of the data tables for the activities students will carry out.

ACTIVITIES

There are three activities that can be scheduled over three days, preceded by introductory discussion and development of predictions and hypotheses. There is also an Extension involving discussion of the inverse square law and the logarithmic scale of decibels.

YOU WILL NEED

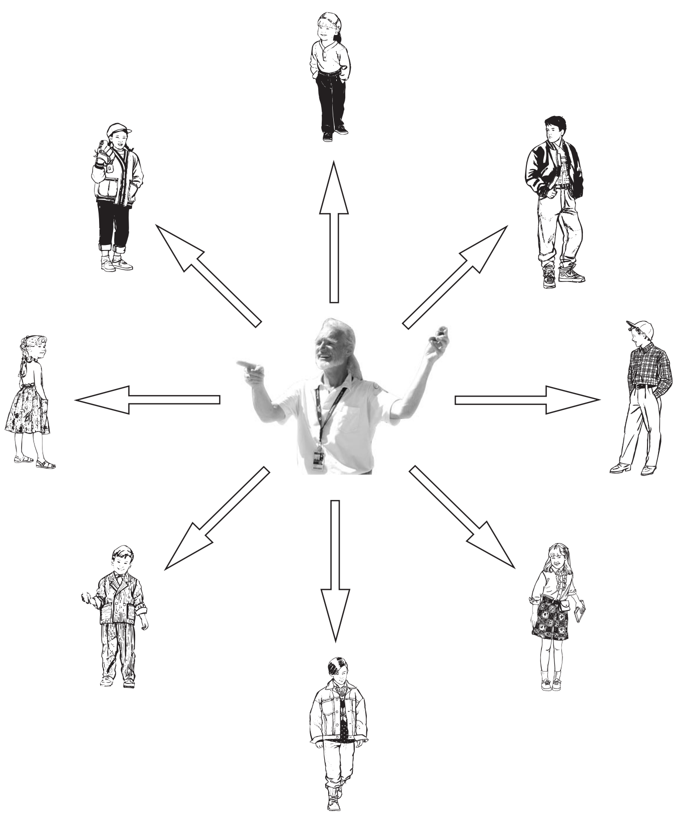
An open area with at least 120 meters of space (such as a football or soccer field); patterns and student directions for constructing a cardstock parabolic dish antenna, student directions for making an antenna from a soda bottle, scissors and X-acto knife, tape, copies of student data tables in which students will record data, metric measuring tapes or trundle wheels, and two or more umbrellas of different diameters (student groups can change variables by trying different sizes of soda bottles and umbrellas). Additionally, you will need a digital wrist watch with a timer mode that can be used to create a repeating beeping timer (set "timer mode" for "1 second," and "CR"–count down, beep, reset).

P R E L I M I N A R I E S

HYPOTHESIS/MATHEMATICAL CONTEXT

(Discussion, Inferences, Predictions)

Out in the field: Ask students to gather around to listen to the sound of the timer (watch) beeping at 1-second intervals. (The beeping timer represents a communication signal sent from NASA scientists on Earth to the spacecraft or a signal sent from the spacecraft to Earth.) Ask the students to predict a distance, in meters, they think they can walk away from the source of the beeping and still hear it with their ears alone; have the students write their predictions in their data tables. Now have them develop a hypothesis about how they think using a parabolic antenna will affect their ability to hear the signal the farther away they walk and why.



A C T I V I T Y 1

CAN YOU HEAR ME?

(Ears Alone)

(a) No Antenna (Umbrella)

Students form a circle around the Sender (teacher or a student) who is the transmitter or spacecraft sending a signal with the beeping timer. They should record the number of meters that they are from the signal to start. Tell the students to raise one hand if they hear the signal. The Sender should turn, timer against body, facing the signal in the direction of each student. Why would the direction the Sender is facing change the strength of the signal that each student receives?

Tell the students to step approximately 1 meter farther away from the Sender after each time they hear the signal, until they reach a distance at which the signal is too weak to hear. Repeat the experiment three times and ask the students to record the greatest distance for each test in their data table. Students should calculate their average distance for the three trials and compare data. Why might there be variation in the point at which different students lose the signal?

(b) Sender with Antenna (Umbrella)

Have the sender tape the watch to the umbrella handle, then repeat the activity as shown in picture. Sender should turn as before. Repeat three times and record greatest distances.

Sender holding umbrella; beeping watch is taped to umbrella handle.

ACTIVITY 2

USING AN ANTENNA

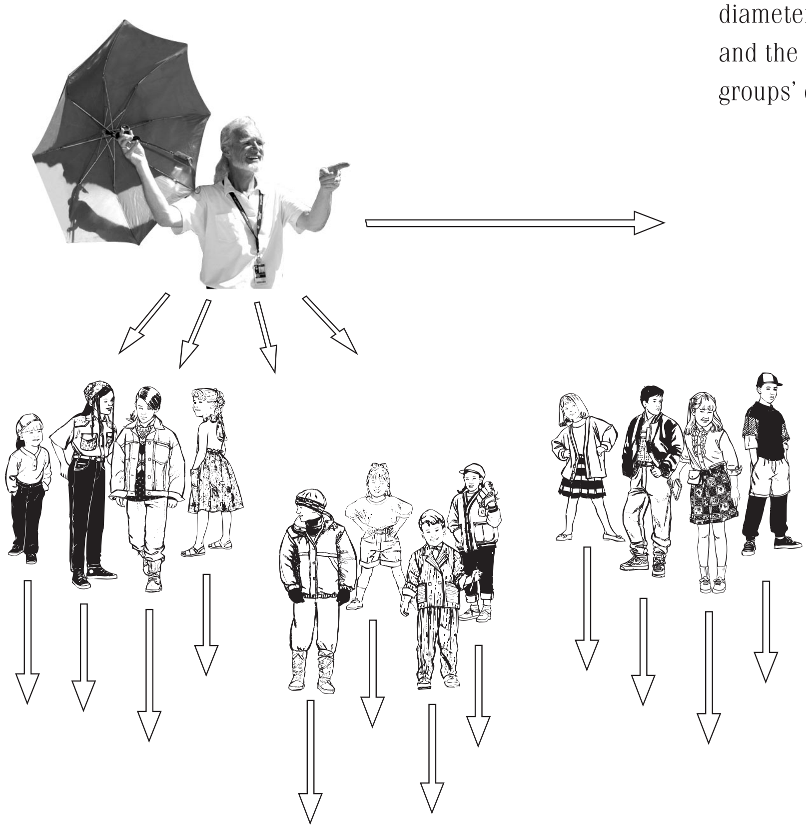
(Ear Antennas and Beeping Watch)

In the classroom, students construct "ear" antennas — cardstock antennas from patterns or antennas made from plastic soda bottles — and then return to the field. Students stand side by side in groups of four across the field, directing their ear antennas toward the Sender with the beeping timer and umbrella antenna. The Sender aims the umbrella handle at each student, keeping the watch in the same position by taping it to the shaft. Students hold their antennas next to their ears and continue to move farther away from the signal each time they hear it. Repeat the experiment three times and ask the students to record the greatest distance for each test in their data tables. Have students calculate their average distances for the three trials. Compare and discuss the observations and the distance data recorded in Activity 1 and Activity 2. How do the antennas increase the distance that the signal can be heard?

ACTIVITY 3

FURTHER EXPLORATION

Does the size of the antenna/umbrella make a difference? Students work in groups of four using two different sizes of umbrellas, a wrist-watch beeping timer, and student-made antennas. Students take turns being the Sender (watch holder), Listener, Measurer, and Recorder. The Sender holds the watch at a fixed height and position as the Listener steps away from the beeping signal until he cannot hear it while using his ear antenna. The Measurer measures the diameter of the antennas they are using and the distance between the two students (Sender and Listener). The Recorder writes down the measurements in the data tables. Repeat the experiment using umbrellas of two different sizes. Try sending the signal from both the umbrella antenna (the Deep Space Network) and the student-made antenna (the spacecraft antenna). The students record and compare differences they observe related to the size of the antennas, then analyze their data to see if there is a correlation between the antenna's diameter and the distance between the Sender (watch holder) and the Listener. Discuss the results and conclusions of each groups' experiment.



Sender with beeping watch taped to umbrella handle moves across line of students.

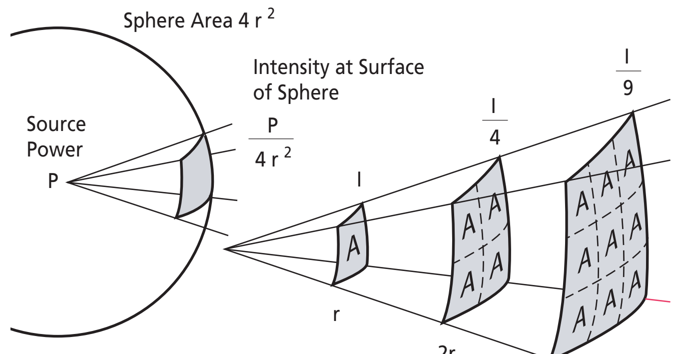
Groups of four students with "ear" antennas move farther away as they hear the signal; students raise their hands each time they still hear the signal.

EXTENSION

Discuss the inverse square law and see how it might apply to the data collected. Students can be introduced to the logarithmic scale of decibels and solve mathematical equations related to it. Research the number of watts of the signal that is sent from the Voyager spacecraft compared to the number of watts received by the Deep Space Network. (Voyager = 13 watts compared to one billionth of one billionth of a watt received by Deep Space Network)

INVERSE SQUARE LAW

The inverse square law applies to both electromagnetic waves and sound waves. Antennas (radio telescopes) on Earth and spacecraft emit electromagnetic waves; a beeping watch emits sound waves. The beeping watch in the activities described here is similar to the emitting antenna or spacecraft; the person listening is the receiver, similar to the receiving spacecraft or antenna. When the distance between the beeping watch and the listener increases, the volume of the sound decreases by the square of the increased distance. If the volume of the sound at distance *r* is *I*, the volume at distance 2*r* is *I*/*r*^2, the volume at distance 3*r* is *I*/*r*^3, and so on.



The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.

LOGARITHMIC SCALE OF DECIBELS

The volume, or intensity, of sound waves can be measured in watts per square meter. The inverse square law can be used easily with these units. However, the preferred units for volume intensity are decibels (abbreviated dB). Decibels do not easily follow the inverse square law because they are logarithmic — every increase by 10 decibels is an increase in sound of 10 times. This means that 10 decibels are 10 times greater than 0 decibels, 20 decibels are 10 times greater than 10 decibels, 30 decibels are 10 times greater than 20 decibels, and so on. Here are the equations to switch between watts per square meter to decibels:

$I(\text{dB}) = 10*\log(I/I0)$

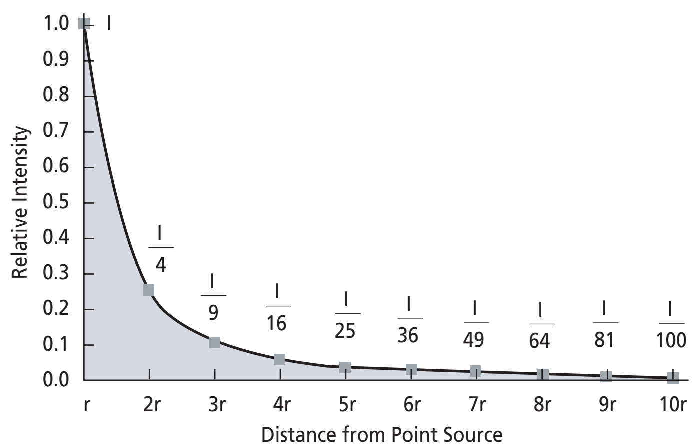
$I = I0*10^{(I(\text{dB})/10)}$

I(dB) is volume intensity in decibels

log is logarithm base 10

I is volume intensity in watts per square meter

*I*0 is the threshold of hearing, 10^–12 watts per square meter



Diagrams courtesy of HyperPhysics ©C.R. Nave, 2002, Georgia State University. Used with permission. HyperPhysics is at http://www.phy-astr.gsu.edu.

STUDENT DATA TABLES

ACTIVITY 1

CAN YOU HEAR ME?

NAME__________________________DATE____________________

Distance Where Signal Is First Inaudible	(a) No Umbrella, distance (m)	(b) Watch with Umbrella, distance (m)
Prediction		
Trial 1		
Trial 2		
Trial 3		
Average of 3 trials		

ACTIVITY 2

USING AN ANTENNA

NAME__________________________DATE____________________

Diameter of Sending Umbrella______________________________

Diameter of Receiving "Ear" Antenna ________________________

Distance Where Signal Is First Inaudible	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

ACTIVITY 3

FURTHER EXPLORATION

NAME__________________________DATE____________________

Diameter of Umbrella 1____________________________________

Diameter of Receiving "Ear" Antenna________________________

Distance Where Signal Is First Inaudible	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

Diameter of Umbrella 2____________________________________

Diameter of Receiving "Ear" Antenna________________________

Distance Where Signal Is First Inaudible	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

EW-2003-02-014-JPL

CARDSTOCK PARABOLIC DISH ANTENNA

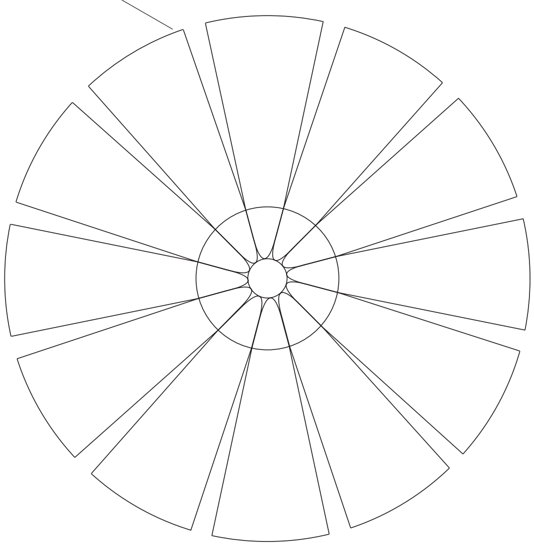
Teacher

Using cardstock, enlarge the antenna pattern twice on a photocopier: once at 165%, then enlarge at 165% again.

Student

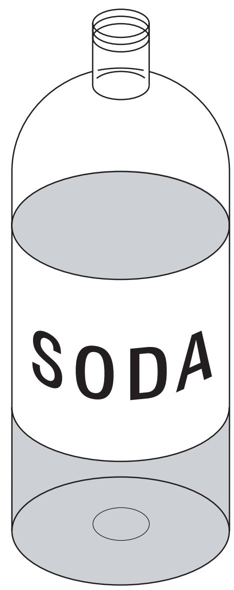
Cut between the petals, stopping at the first circle. Bring the petals together, overlapping them slightly and taping them on the back, forming a curved dish. Cut a small hole in the center of the dish at the innermost circle, then reinforce the center hole on the back with tape.

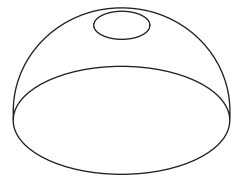
Cut here

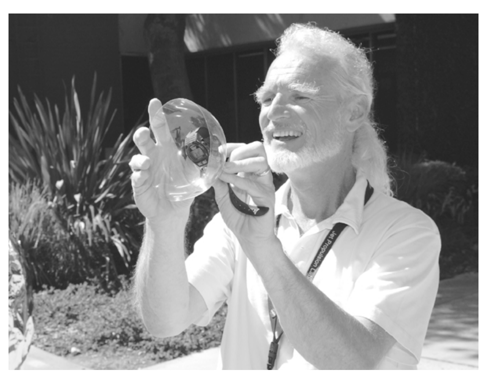


SODA BOTTLE PARABOLIC DISH ANTENNA

Use an X-acto knife (caution — very sharp) and/or scissors to cut the top off a plastic soda bottle above the label and at the bottom of the neck. This cut-off section will become your parabolic dish antenna. Trim off any rough edges with the scissors.







Example of "ear" antenna made from soda bottle.